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SOIL CORROSION SURVEYS

The following abstracts and summaries have been prepared from recent publications relating to methods of determining the corrosivity of different soils with respect to ferrous metals and are intended to give a fairly complete outline of what has been accomplished in this field. Where more detailed information is desired, the unabridged articles should be consulted.

Bureau of Standards publications referred to may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D.C., at the prices indicated below, or may be found in libraries in many cities. A complete journal reference for each paper is given in the text. Where the price is noted, the publication may be purchased from the Superintendent of Documents. The prices quoted are for delivery to addresses in the United States and its possessions, and to Canada, Cuba, Mexico, Newfoundland, the Philippines, and the Republic of Panama. When remitting for delivery to other countries than those, include in your remittance one-third of the total cost of publications to cover postage. Remittances should be made payable to the "Superintendent of Documents, Government Printing Office, Washington, D.C." and sent to him with the order.

Shepard, E.R., Pipe line currents and soil resistivity as indicators of local corrosive soil areas, BS J. Research 6, 683 (1931); RP298, 15 cents.

Denison, I.A., Correlation of certain soil characteristics with pipe line corrosion, BS J. Research 7, 631 (1931); RP363, 5 cents.

Denison, I.A., Methods for determining the total acidity of soils, BS J. Research 7, 413 (1933); RP539, 5 cents.

1. Denison, I.A., Correlation of certain soil characteristics with pipe line corrosion, BS J. Research 7, 631 (1931); RP363.

Corrosion experienced in the operation of a group of pipe lines in Ohio was found to be related to the kinds of soil which occur along a 32-mile section of the lines. Sandy and sandy-loam

soils not underlain by glacial material apparently have little corrosive action. A satisfactory correlation was found to obtain between the exchangeable hydrogen present in the soils and corrosiveness as indicated by the quantity of pipe replaced in 1,000-ft. intervals.

An accelerated laboratory test of soil corrosiveness involving the corrosion of a steel disk in contact with moist soil is also described. The results obtained paralleled the quantity of pipe replacements fairly closely in the case of heavy soils.

See also The Corrosion of Ferrous Metals in Acid Soils, Denison, I.A., and R.B.Hobbs, BS J.Research 13 125 (1934);RP696.

2. Smith, W.T., Analyzing the merits of soil corrosion survey work as developed for the Amarillo-Denver Line, Western Gas 7, 30 (Feb.,1931).

The relative corrosiveness of the soil at various points along a pipe line right of way may be estimated in advance as a basis for the specification of the degree of protection to be applied in different sections. The most commonly used and generally accepted means of estimation is based upon simple observation of surface conditions. As an alternative, a detailed soil-corrosion survey involving simultaneous consideration of chemical and topographical characteristics was first employed in the construction of the Amarillo-Denver natural gas pipe line. The inspection of this line at 66 points by the American Gas Association two years after installation affords a basis for studying the relative merits of the two methods. Consideration of available data led the author to the following conclusions:

(1) The substantial accuracy of the results of a soil corrosion survey as used by Ford, Bacon & Davis, Inc., is confirmed, for alkali soils.

(2) The probable accuracy of such a survey in other soil conditions is indicated.

(3) The specification of the degree of protection to be used on a pipe line is more exactly in accord with the actual requirements when based on a soil corrosion survey than when based upon surface inspection alone.

(4) The variation from the degree of protection necessary, as indicated by actual inspection after service, tends toward provision of excess coating in the case of a soil corrosion survey and toward inadequate protection in the case of surface inspection alone.

(5) Agreement by independent observers as to the degree of corrosiveness of the soil at any location is not absolute even when based on inspection data of pipe after service.

(6) It is unsafe to base a decision to eliminate protection at any point on the old method of simple inspection of the surface of the ground alone.

(7) It is relatively safe to base specifications of pipe protection on the results of a thorough soil-corrosion survey.

(8) Substantial agreement in the comparative rating of soil samples as to relative corrosiveness, although a matter of judgment, is possible by independent workers.

(9) Using the data from a soil-corrosion survey, substantial agreement is possible in the independent specification of the degree of protection for specific sections of pipe lines.

(10) In the instance studied, soil-corrosion survey specifications would have entailed an expenditure for pipe protection of 6.4 percent more than actually required. The actual construction program (although only in part substituting simple surface observation for a soil corrosion survey) expended only 75.1 percent of the amount actually required for adequate protection.

(11) This study has shown no one factor or small group of factors affecting corrosion which may safely be taken as an index of the comparative corrosiveness of soils at various locations.

3. Ewing, S., Research Associate, American Gas Association, A.G.A.-Bureau of Standards field study of long gas lines, Am. Gas Assn. Month. 13, 70 (Feb., 1931).

An inspection of the Amarillo-Denver line at 65 locations, two years after installation led the author to the following conclusions.

The data fail to indicate that light coatings such as paints and cut-backs have any protective value. The light, cut-back, coating used on some portions of the line was found to be in all stages of disintegration. Where it was in good shape, it is doubtful if bare pipe would corrode, and where the soil was corrosive the pipe was pitted. A cold coat containing asbestos fiber, used on some portions of the line was examined in only three places, which is not sufficient for a positive conclusion.

There does not appear to be any relation between the electrical resistance of these coatings and their condition, the resistance being very low wherever it was measured. The condition

of these coatings does not appear to be related to either the colloidal content of the soil or its specific resistance when saturated.

The results of this study indicate that if an enamel is used as a pipe coating it should be hard, because the harder the enamel the better it resists soil action. The only limit to hardness is the tendency of the enamel to crack. A much harder enamel can be used in warm weather, so it is a decided advantage to apply it then.

There is a fair correlation between the soil types and the recommendations resulting from the corrosion survey. In order to make coating recommendations in this region as accurate as those made for this line the following procedure is sufficient: Make a soil map of the line and (2) measure the resistivity of a number of soil samples, taken with proper care along the line.

4. Shepard, E.R., Pipe line currents and soil resistivity as indicators of local corrosive soil areas, BS J. Research 6, 683 (1931); RP298.

The present tendency in the protection of pipe lines against soil corrosion is away from a uniform coating for the entire length of the line and toward the application of coatings selected with respect to the corrosive character of the soils involved. This calls for a knowledge of varying soil conditions and a means of locating local corrosive soil areas. Such areas, commonly termed "hot spots", are prevalent in many types of soils, and it is in these regions that pipe lines suffer the greatest deterioration. The location of such corrosive areas is a matter of considerable importance, both with respect to the selection of coatings for new pipe lines and the reconditioning of old ones.

An extensive investigation of a dozen pipe lines ranging from the Gulf coast to southern Kansas revealed an apparent correlation between pipe-line currents, soil resistivity, and corrosion. Galvanic currents of measurable magnitudes were found to be flowing on all pipe lines examined. As a rule, lines were found to be collecting current in areas of normal and high soil resistivity and losing current in areas of low resistivity. Many cases of abrupt loss or discharge of current occurred in soils of unusually low resistivity. In such areas the pipe lines were found to be badly corroded.

Although no direct relation was found to exist between electrical resistivity of soils and their corrosiveness, abrupt changes in resistivity and unusually low resistivity were found to be significant with respect to corrosion. Soils having a resistivity of about 500 ohm-centimeters or less were invariably

found to be highly corrosive. A better relation between resistivity and corrosiveness exists in alkali than in acid soils.

To expedite the measurement of soil resistivity, a simple piece of apparatus was developed, consisting of two metal-tipped oak rods with a milliammeter mounted on one and a small flashlight battery on the other. By measuring the apparent resistance between the metal terminals, the approximate resistivity of the soil can be calculated if the constant of the apparatus is known. Since polarization is largely a cathode effect, it can be partly eliminated by making the cathode terminal much larger than the anode, thereby reducing the current density on it. A low resistance meter, such as a milliammeter, is found to be preferable to a voltmeter, as with the former practically the full voltage of the test battery is applied between the electrodes, irrespective of the meter reading, while with the latter a large part of the battery voltage is consumed within the meter itself.

This apparatus permits of making frequent and rapid tests of earth resistivity along a pipe line or along a projected pipe line. Although it is not claimed that absolute values of resistivity are obtained with this apparatus, the results are sufficiently accurate for all practical purposes provided the soil is not too dry. It is important that earth be tested at the pipe level and where there is sufficient moisture to afford nearly maximum conductivity. Damp soil which will pack in the hand will usually show conductivity approaching that in a saturated condition.

The technique of surveying pipe lines for galvanic currents and soil resistivity is discussed.

5. Gill, S., and W.F. Rogers, Gulf Oil Co.'s research dept., Houston, Texas, Relation of long line currents to soil corrosion, Physics, 1, 194 (September 1931).

"Stray currents" from street electric railways and the like give rise to rapid corrosion of buried pipe lines. A type of currents similar to "stray currents", but which occur at long distances from any possible external source of electric current, has been found on pipe lines. These currents are known as "long line currents" and are supposed to originate between the soil and the pipe. They frequently follow the pipe for miles without any change in amperage. To determine possible influence of these currents upon corrosion, measurements of their value were made on an 8-inch oil line upon which much corrosion trouble had been experienced. The line was removed from the ground and the extent of corrosion determined by inspection. Electrical resistivities of numerous samples of soil were determined.

From the data obtained, the following conclusions are drawn:

(1) Discharge or accumulation of electric currents of the class which have been termed "long line currents" is, in general, without influence upon corrosion of buried pipe lines.

(2) Electrical resistivity of soil correlates to a certain extent with corrosion of buried pipe; the relationship is not sufficiently consistent to be of practical value.

(3) There is no consistent relationship between soil resistivity and the accumulation or discharge of "long line currents".

A more detailed discussion of the several classes of current affecting pipe lines will be found in the paper by Logan, Rogers, and Putnam "Pipe Line Currents," Trans. A.P.I. Meeting, Section IV, 116 (1930) and also in a paper by Gill and Rogers, "Electric currents carried in lines", Oil and Gas Journal, 29, 158 (1930).

6. Logan, K.H., Bureau of Standards, Soil Corrosivity Surveys, Am. Pet. Inst. Production Bul. 207, 142 (June 1931). Oil and Gas J., 30, 48 (June 4, 1931). Pipe Line News (Dec. 1931).

The author states briefly the essential features of a number of tests for the corrosiveness of soils now in use in various parts of the country. The details of manipulation depend on the operator. The following general conclusions are given.

Most, if not all, of the methods for identifying corrosive soils have been shown by their originators to be reasonably satisfactory under some condition. None of the methods have been used extensively enough to permit defining their limitations. The best way to do this would be to try out each method along a number of pipe lines in various parts of the country, determining at the same time the condition of the line. Until the results of such tests are available, it would probably be advisable for the soil survey engineer to check his results by the use of two widely different methods, selecting the methods after determining whether the soils are acid or alkaline. He might start with a method involving soil resistivity, indications of which will probably be significant if the resistivity is low. If the resistivity is high, the total acidity of the soil should also be investigated. Since soil conditions may change radically with the season, it will be well to give careful consideration to topography, drainage, and rainfall. The services of an expert familiar with the identification of soils will reduce the number of tests necessary and the chances that some corrosive soils will be missed. If due care is used, it may be expected that a very large percentage of the corrosive and non-corrosive soils will be located.

A bibliography is given.

7. <u>Shepard, E.R., Bureau of Standards, Determining the corrosivity of soils, Oil and Gas J., 30, T-40 (June 4, 1931).</u>

Although in general the alkaline soils of the West and certain southern soils appear to be the most destructive to pipes, there are no geographical limits to the areas in which acute corrosion may occur.

The experience of nearly every pipe line company and utility operator, which is also supported by the Bureau's data, indicates that a large proportion of the destructive corrosion occurring on their systems is confined to relatively small areas. The problem of locating or predetermining such areas, particularly the so-called "hot-spots" or excessively corrosive soils, is of great importance to the pipe owners, both in connection with the protection of new lines and the reconditioning or repair of old ones.

No satisfactory method of predetermining the corrosivity of soils has yet been discovered, although several methods which are more or less applicable to certain types of soils have been proposed and used. Chemical analyses have generally proven disappointing although in some instances such tests are indicative of corrosive properties. A brief description is given of several tests which have recently been proposed for determining soil corrosivity, all of which involve electrical resistivity as the chief factor.

An analysis of the Bureau of Standards corrosion data indicates that for alkaline soils there exists a fair correlation between corrosivity and electrical resistivity, while for acid soils there appears to be no satisfactory relation.

This observed relation of resistivity to corrosivity in many soils is confirmed by a study which the Bureau of Standards carried out along a number of pipe lines in the southern states during the spring and summer of 1930. The primary purpose was to determine the relation of electric currents on pipe lines to corrosion, but measurements of soil resistivity also were made and these added greatly to the value of the investigation.

Measurable currents of galvanic origin were found on all pipe lines examined and marked variations in soil resistivity were discovered along most of the lines. In general the collecting areas, or those sections in which current flowed from the soil to the pipe, were regions of normal or high resistivity, while the discharge zones were usually relatively small in extent and were regions of low resistivity. On eight of the nine lines explored,

abrupt changes in soil resistivity from high to low values were accompanied by unusually high rates of discharge of current from the pipe to the earth, and in such areas excessive corrosion was usually found to be in progress. In short, hot spots or excessively corrosive areas of limited extent can be located by either a study of galvanic currents on the line or by the measurement of soil resistivity. While no direct quantitative relation was found to exist between corrosion and soil resistivity it is significant that soils having a resistivity of about 500 ohm-cm. or less were invariably found to be highly corrosive.

Until further correlations are obtained, covering a wide variety of soil conditions, resistivity values should be considered as indicative of corrosive areas only when the resistivity is unusually low or where abrupt changes are observed.

8. Weidner, C.R., and L.E. Davis, The Prairie Pipe Line Co., Relation of pipe line currents and soil resistivity to corrosion. Am. Pet. Inst. Production Bul. no. 208, 36 (December 1931). Oil and Gas J., 30, 41 (Nov. 12, 1931).

The authors describe the results of soil resistivity and pit depth measurements on 58 miles of 8-inch oil pipe lines in Oklahoma. Long-line currents were measured on 11.4 miles of the line. The apparatus and methods used were the same as those employed by Shepard. The authors summarize their findings as follows:

Long-Line Currents

Although the long-line current data are incomplete, the following observations appear warranted:

(1) The magnitude and fluctuations of long-line currents were greater than those observed by previous investigators. A maximum of over 6.85 amperes was observed in several places.

(2) Long-line currents are not constant, but may vary from time to time, due probably to moisture content of the soil, terrestrial magnetic currents, solar activity, and probably other causes.

(3) The depth of pits seems to be dependent on the magnitude of the current. Taking into consideration the age of the pipe, 8 years, and the low resistivities in many places, the pit depths were not large. However, an average of the current measurement showed about 0.5 ampere, which probably was not large enough to cause serious loss of metal.

(4) Loss of current is not always indicative of serious pitting, unless concentrated at points of low resistivity. Conversely, when the line is picking up current, it can not be definitely said that there will be no pitting. Pitting may occur along such stretches if there is sufficient leakage at points of low resistivity.

(5) Long-line current measurements furnish a rapid and inexpensive method of examining existing pipe lines to determine the portions that need reconditioning. Such measurements must, however, be supplemented with resistivity measurements.

(6) In attempting to take measurements of long-line currents on a pipe line paralleling a telegraph line within a few feet, evidence of stray current of considerable magnitude was found.

Soil Resistivity.

(1) It requires extreme care to obtain the resistivity, or even the relative resistivity, of the soil along a pipe line. An experienced observer is required for accurate measurements.

(2) Shepard's apparatus is more useful to discover corrosive soil than the data presented indicate.

(3) There is not much pitting in sand, gravel or rocks where it is impossible to measure resistivity with Shepard's apparatus.

(4) Clays with extremely low resistance were always wet enough even in summer to obtain good resistivity measurements.

(5) Where deep pits were found, soil of low resistance usually could be found at some depth.

(6) Deep pits did not always coincide with soil of low resistance, but frequently were found in the next joint.

(7) The resistivity of the soil below pipe depth is of some importance. Such observations sometimes discover soils of low resistance containing salts, which are absorbed by the top soil.

(8) In soils of high resistance a hard rust scale sometimes forms, which seems to protect the pipe against further corrosion.

(9) In soils of low resistance, where pitting is rapid, there is no scale or rust formation. The pipe is wet most of the time, and the corrosion products are white, yellow or green.

Conclusions

The data which have been presented indicate many variations and irregularities. This may be due largely to trying to analyze one variable, such as soil resistivity, when several are involved in the determination of soil corrosivity. Errors in observation must also be considered. No definite conclusions can, therefore, be drawn until more data are available. However, taking into consideration these limitations, the authors have concluded tentatively that:

(1) There is some correlation between long-line currents and corrosion. In general, galvanic currents gradually accumulate on pipe lines through soils of high resistance, and in most cases discharge from the lines in soils of low resistance. If current density is relatively high and the discharge is abrupt, deep pitting is usually experienced.

(2) There is considerable correlation between depth of pits and resistivity. This is of practical value in soil corrosivity surveys. Soil resistivities of less than 1,000 ohms are usually indicative of severe pitting. If due care is used, it may be expected that a large percentage of the corrosive soils will be located.

(3) The results of this investigation lead to conclusions that agree closer with Shepard's than those of Gill and Rogers.

Discussion of Weidner and Davis paper

Am. Pet. Inst. Production Bul. no. 208, 45 (December 1931).

Gill, Stanley - Gulf Oil Companies

A detailed analysis of the data is given and the following conclusions reached:

A protection program predicated upon the resistivity classification would involve coating 26 percent of the total length of pipe, and would result in protection of 74.7 percent of the points on which actual corrosion was experienced. A "no coating" program would involve no expenditure for resistivity survey or protective coating, but would leave unprotected all of the corrosive spots. In practical operation many of these corrosive spots could be

predetermined by experience; undoubtedly a considerable number are located in salt water drains, stream crossings, cinder fills, and the like. Such points would obviously merit protection, even without data on soil resistivity. It is our opinion, which is supported by the data presented by Mr. Weidner and Mr. Davis, that resistivity surveys cannot be economically used as the basis for pipe line protection programs.

Fitzgerald, Charles - The Pure Oil Pipe Line Company of Texas.

The results of a soil survey along 88 miles of pipe line in East Texas are described. Following are some of the conclusions.

The quantitative correlation which exists between resistivity and corrosion should not be anticipated between long-line currents and corrosion. Total corrosion and pitting rate, being functions of both local action and long-line currents, are dominated by the properties of the soil as expressed by resistivity. The ratio of long-line current effect to local action varies greatly; and, therefore, the former can have no exact relation to total corrosion or pitting rate. Resistivity measurements indicate where there is a tendency to corrode under conditions of sufficient moisture. Long-line current measurements show whether corrosion is active at the time, and define the limits of the section affected. If it could be determined for a specific set of conditions, the ratio probably would remain fairly constant.

For practical usefulness of these methods in the maintenance of pipe lines, the following procedure is suggested:

(1) Find the hot spots by soil resistivity.

(2) Check them by current measurements.

(3) Apply insulation until the current has been reduced to negligible amounts.

(4) Take all electrical readings when the soil is moist.

Logan, K.H., and S.R.Shepard - U.S.Bureau of Standards.

Soil characteristics vary so in different localities that what may be applicable in one territory may be found entirely impracticable in another. The correlations found by Mr. Weidner and Mr. Davis, while by no means perfect, indicate a worth-while relation between soil resistivity and pipe life in the territory covered by their tests. Pipe line currents appear to have a directional value, and no doubt can be used in some locations as an auxiliary to the measurement of soil resistivity in locating corrosive areas.

A very satisfactory correlation between soil resistivity and pipe life has been reported by A. B. Allyne, Southern Counties Gas Company, Los Angeles, in the Gas Age Record, August 22, 1931. It is apparent from Mr. Allyne's data that the alkali soils of the West lend themselves particularly well to the resistivity test, and that average pipe life can be predicted with a fair degree of accuracy by this method. In other soils, such as those in which Mr. Weidner and Mr. Davis worked, the relation is somewhat less pronounced; while in some regions it may be possible that no worth-while relation exists. Other pipe line companies are making similar tests in other territories, and it should be a matter of a comparatively short time before we can say rather definitely in what territories and in what types of soil the resistivity test is of practical value.

Most of the electrical tests which have been devised to determine the corrosive properties of soil involve soil resistivity in one way or another, and several of the methods compared by us appear to give substantially the same results; i.e., we can usually discriminate between highly corrosive and non-corrosive soil by any of these electrical tests. Until it has been demonstrated that some more precise or complicated measurement is of greater significance than those obtained with the simple apparatus now in use, we see no reason for resorting to greater expense and pains in determining soil properties.

9. Allyne, A.B., Chemist, Southern Counties Gas Co., Los Angeles, Calif., Distribution soil surveys by the Shepard rod method, Western Gas, 7, 127 (August 1931); also Gas Age Record 69 269 (August 22, 1931).

In order to get a check on the apparatus before actually starting the survey, a number of locations were picked in which the life of steel pipe was actually known from past experience. After collecting a large number of these readings, it was found that in most cases at least, there was a marked agreement between the resistivity findings and the actual life of pipe. These data were then used to establish the scale readings in terms of life of pipe.

This segregation gave the following range of readings for three ranges of pipe life.

Rod readings, ohm-cm	Probable life of bare steel pipe, years
0-1000	0-9
1000-2500	9-15
2500-10,000	15 or more

It has been found that a single operator can make about 25 to 30 tests per day, depending upon the mileage covered and the nature of the soil into which the auger must penetrate. At this rate it is estimated that the city of Santa Barbara can be completely surveyed in from a month to six weeks.

The cost per test has been roughly calculated to be between 25 and 30 cents. This is total cost and includes equipment, salary, transportation and technical supervision. A rapid computation will show the entire cost of the survey to be negligible in comparison with the value of the information it will make available.

The soil maps resulting from these surveys will be used as atlases for future pipe protection work. In addition to this, as a second check, it is planned that all ditches in which pipe is to be laid will be tested every 50 feet prior to installation.

It is roughly estimated that the survey of our entire system can be completed in somewhat less than two years. So many factors influence this time period that no more definite a figure can be estimated until the work has further progressed.

At this writing it may be said, in conclusion, that the Shepard rod method appears to be a simple and rapid medium for obtaining the desired approximation in pipe line protection work. Future developments and the completed maps themselves are awaited with no little interest.

10. Turner, C.F., The East Ohio Gas Co., Experiments with the conductivity method of measuring soil corrosivity, Am. Gas Assn. Distribution Conf., Birmingham (April 6, 1932).

Conclusions. (1) The conductivity method of forecasting the degree of corrosive action of our acid soils on steel pipe has shown a number of inconsistencies sufficient to indicate that it is by no means infallible. But on the other hand many, many cases have been found where low resistances are coincident with bad corrosion and pitting in the space of a comparatively few years, even months. The preponderance of these cases lends encouragement to the work.

(2) Moisture is one variable which in our opinion must be considered in interpreting from resistivity readings the probable life expectancy of pipe. We cannot at this time agree that measurements made at saturation furnish the proper criterion by which to fix the degree of corrosivity; an array of evidence to the contrary must be considered.

Readings taken in a ditch following a rain are no more consistent than when taken in the same ditch which appears dry, but they are often of an entirely different order of degree - which are we to take as the right ones?

(3) Experience to date indicates that where resistivities up to 200 ohm-cm are encountered the pipe will last about 2 years before a puncture may be expected. The survey on the 16-inch line and numerous other tests made in the City lead to observation that whenever a soil shows a resistivity of about 1200 ohm-cm the pipe has an age very close to 15 years and there are apt to be numerous pits more than two-thirds through the pipe.

(4) Summarizing all the work that we have done with the conductivity method of determining the corrosiveness of the acid soils with which we are dealing, we are convinced that while there are many things in the results obtained which remain unexplained we have found it very useful in helping to determine pipe failures. We also believe that a survey over a proposed right-of-way for a pipe line is well worth the time and money spent in making it, and we propose to carry out such a plan whenever we have occasion to renew or relocate sections of our transmission system.

11. Denison, I.A., Methods for determining the total acidity of soils, BS J. Research 10, 413 (1933); RP539.

Titration of soil extracts to an inflection in the titration curve was found to be a practical means of determining their total acidity. Ten-grain samples of soil ground to pass a 1-mm sieve were placed in a series of 200 x 25 mm pyrex test tubes. Increasing amounts of 0.045 N solution of $Ca(OH)_2$ in 1N NaCl were then added in increments of one milli-equivalent of alkali per 100 grams of soil, and the volume brought to 50 ml with 1N NaCl solution. The tubes were then stoppered and shaken vigorously three times daily for a period of three days. The pH values of the extracts were determined colorimetrically, each indicator having been adjusted to the acid, mid-point and alkaline parts of its range. The pH values were plotted against the amounts of alkali added, the point of neutralization being indicated by the inflection in the curve.

The method of Page and Williams, which is based upon the principle of base exchange, is shown to be well adapted to measuring the acidity of organic soils to which the titration method does not apply.

12. Ewing, S., Corrosion surveys for transmission lines and distribution systems, Proc. Am. Gas Assn. (1934).

This paper is the result of an attempt to determine the usefulness of the several known methods of making soil corrosivity surveys by comparing the results of the use of these surveys along a pipe line with the replacement record of that line.

All electrical methods of determining the corrosivity of soil yield results which depend almost entirely on soil resistivity. The only chemical property of the soil which was investigated was the acidity of the soil. The types of soil traversed by the pipe line were determined by methods of the Soil Survey of the U.S. Dept. of Agriculture. The soil acidity is shown to be entirely useless for this particular pipe line system as a means for predicting where corrosion will occur. With respect to the determination of the resistivity of the soils along the line the author says "It may be that in many cases such a soil survey would prove economical but the saving is small and the method certainly cannot be considered satisfactory."

With respect to the correlation between soil types and corrosion the author states "There are real differences in the corrosiveness of soil types. If the soil types had been arranged in order of their corrosiveness as determined by repair records and if the economic method (of protecting the line) had been applied, a reduction in operating costs of about 24 percent over the cost of coating the entire system would have been effected." (In many instances, however, the corrosiveness of a soil type cannot be readily determined by reference to repair records).

"It was found that the average acidity of each soil type when combined with the average resistivity of the type will increase the accuracy with which we can calculate the percentage of pipe repaired in each soil type. The relation is

$P = \frac{8000\ (A-5)}{R}$ where P is the percentage of pipe repaired in each soil type, A is the average acidity of the type, and R is the average resistivity of the type.

This combination of methods will probably effect appreciable savings on any pipe line in eastern United States, if used at the time the line is built. It will certainly require some modification in western soils.

The author gives the following formula for calculating the annual cost of a pipe line

$$\left[C_L + K_c f(x)\right] (R+F_n) + \frac{K_L}{n} \left[l_T - f'(x)\right] + D = \text{annual cost.}$$

where C_L = initial total cost of the pipe line exclusive of the coating,

K_c = cost of coating a unit length of line initially e.g. (100 ft.) = \$15.00

f(x) = the number of unit lengths that are coated (function of the value of the measure of corrosiveness)

R = utilities fair rate of return, e.g. 6 percent.

F_n = sinking fund factor =

$$\frac{i}{(1+i)^n-1}$$

If n = 30 years and the interest rate, i = 6 percent F_n = 1.265 percent.

K_L = cost of repairing a leak by uncovering a unit length of pipe, repairing the pipe or replacing it and applying a coating which will protect the pipe for n years e.g., \$200.

n = expected life of line (average is taken as 30 years for these lines).

l_T = total number of unit lengths repaired.

f'(x) = the number of unit lengths on which repairs would have been eliminated by coating. (Function of the measure of corrosiveness).

D = annual cost of operating the pipe line exclusive of coating, pipe and leak costs.

The annual cost is exhibited as a function of x, which is the value of the measure of corrosion beyond which coatings are applied. It may be acidity, resistivity, or any other property of the soil which is used to decide where coatings will be used. If we disregard C_L and D that is to make them equal to zero, the expression may then be called "The annual cost of combating corrosion". It should be clear that these are merely assumed costs and not the actual repair and coating costs on this pipe line system.